VERSION OF SPECIFICATION WITH MARKINGS TO SHOW CHANGES MADE

METHOD AND DEVICE FOR CONTROLLING MOTORS ~~A SYNCHRONOUS MOTOR WITH PERMANENT MAGNETS~~

[0001] This application is a national stage filing under 35 U.S.C. § 371 of International Application No. PCT/CH2005/000064, filed on February 4, 2005, which claims the benefit of priority to U.S. Provisional Application No. 60/542,349, filed on February 6, 2004.

TECHNICAL FIELD ~~OF THE INVENTION~~

[0002] The present invention ~~is in the field of~~ generally relates to the control of ~~a synchronous motor with permanent magnets~~ motors. ~~It relates, more~~ More particularly ~~to an electronic device and~~, the present invention relates to a method and a device for controlling ~~the same.~~ a synchronous permanent magnet multiphase motor.

BACKGROUND ~~OF THE INVENTION~~

[0003] Synchronous motors with permanent magnets, such as stepping motors, hybrid motors, or direct current motors with no commutating element, are currently well known and used to replace direct current motors with a commutating element, the latter having a relatively short lifetime because of friction generated on the commutating element ~~itself~~ by ~~the~~ carbon brushes.

[0004] In ~~these~~ motors with permanent magnets, an electronic phase switching circuit is necessary to replace the commutating element function. ~~Since this type of motor is~~ In synchronous motors, the rotor speed is the same as that of the rotating stator field. ~~However, when~~ When the commutating element is removed and replaced with an electronic circuit, it is necessary to determine the position of the rotor for the control logic to be able to perform the switching at the right time. This is usually achieved with Hall effect probes or optical sensors, which are also called direct sensors.

[0005] This type of direct sensors has some drawbacks. First, their costs have a non-negligible impact on the whole cost of the motor. ~~Second, the mounting thereof means that some~~ This problem can be partially solved by using a low resolution position sensor as described in U.S. Patent No. 6,653,829. In this case, however, a state filter must be associated with the sensor to compensate for its low resolution. Secondly, space has to be especially provided ~~for,~~ not just for the sensors themselves, but also for the related electric connecting means. Therefore, the assembly of such motors is much more complex and time consuming. Finally, the reliability of the system is ~~thereby~~ reduced.

[0006] Some existing systems propose to overcome these drawbacks and provide a method and/or a device for controlling a synchronous motor with a permanent magnet with no direct sensors. This is ~~particularly~~, for example, disclosed in ~~the~~ U.S. ~~patent~~ Patent No. 6,326, 760, or No. 6,005,364, which ~~describes~~ describe a method and a device to determine the speed of the motor by measuring the induced voltages, in at least two phases, when the driving power in said phases is turned off. However, ~~the~~ such a method ~~described here above has~~ suffers from the following main drawback. Since the

motor with variable load cannot be reliably started by means of a closed loop working in function of the position, this method requires an open-loop starting algorithm for the motor to reach a speed level that is high enough to: 1) create a motion with sufficient kinetic energy to prevent the motor from being stopped by the load between two steps of the control algorithm, and 2) generate induced voltages with a sufficiently high magnitude to allow the rotor position to be determined and thus, the motor to be speed and/or torque controlled.

SUMMARY~~ OF THE INVENTION~~

[0007] ~~It is therefore an object~~ Embodiments of the present invention [[to]] provide a method and an electronic device ~~and a method~~ for controlling a synchronous motor with permanent magnets that do not suffer from the disadvantages described above. In particular, with the ~~device and~~ method ~~according to~~ and device consistent with embodiments of the present invention, it shall be possible to determine the position of the motor even at near-zero speeds. A near-zero speed means that, even when the motor is blocked because, for example, ~~because~~ the generated torque is too low, successively turning on and off driving currents will bring about an oscillating movement of the rotor around its rest position and thus produce induced voltages, which are high enough to allow ~~to determine~~ determination of the position of the rotor.~~ These and other problems are solved by the device and method as defined in the independent claims. Advantageous embodiments of the invention are given in the dependent claims.~~

[0008] ~~The~~ Embodiments of the present invention ~~is based on the idea to~~ provide methods to measure induced voltages with ~~the highest possible~~ a high sensitivity, to

determine ~~the rotor~~ a position and/or a [[rotor]] speed of the rotor from the measured induced voltages, and then to ~~enter said~~ use the determined ~~rotor~~ position and/or ~~rotor speed into a state filter which delivers a filtered rotor position and/or a filtered rotor speed that allow~~ speed of the rotor to control the power of each phase of the motor. ~~The~~ Methods consistent with the present invention may be used for any synchronous motor, be it a two-phase or multiple-phase, unipolar or bipolar motor, and controlled with or without pulse-width modulation.

[0009] Embodiments of the present invention also relate to a method for controlling a synchronous permanent magnet multiple-phase motor, where the motor has multiple phases and has a rotor. The method includes ~~The inventive method for controlling a synchronous permanent magnet multiple-phase motor, comprises the steps of: - determining a frequency optimized in function of the characteristics of the motor, said optimized frequency being able to be made constant or variable depending on the status of the motor, -~~ controlling [[the]] drive ~~current~~ currents supplied to the phases of the [[each]] motor phase by ~~cutting it~~ turning the drive currents off ~~totally or partially~~ at ~~said optimized~~ a predetermined frequency; ~~, - virtually simultaneously measuring the~~ measuring, at said predetermined frequency, induced voltages of at least two of the phases of the motor ~~phases~~, when the [[power]]drive currents in said ~~motor~~ at least two of the phases [[is]]are turned off, with a ~~sufficiently high~~ sensitivity sufficient for obtaining significant voltage values at a near-zero ~~to be able to determine a rotational~~ speed of the rotor; ~~motor that is close to zero, - sampling the measured induced voltages at said optimized frequency, -~~ determining a ~~the rotor~~ position and/or a ~~the rotor~~ speed of the

rotor from said measured induced voltages; ~~signals resulting from said samples,~~ filtering the ~~entering said determined rotor~~ position and/or the ~~said determined rotor~~ speed of the rotor with ~~into~~ a state filter to obtain a filtered rotor position and/or a filtered rotor speed; and ~~which delivers a filtered rotor position and/or a filtered rotor speed,~~ adjusting the drive currents ~~current as a function of said~~ according to the filtered rotor position and/or filtered rotor speed.

[0010] Consistent with embodiments of the present invention, an electronic device for controlling a synchronous permanent magnet motor with at least one phase, a coil, a rotor, and a motor driver includes ~~The electronic device according to the invention comprises:~~ detection means~~, which are~~ connected to the at least one phase ~~phases~~ of the motor ~~and deliver~~ for generating signals that represent induced voltages of the at least one phase of the motor ~~phases~~, said detection means having such a ~~high enough~~ gain ~~to provide significant output~~ that the signals representing the induced voltages are significant even if [[the]]a speed of the rotor is near-zero, and a control circuit connected to said detection means and to the motor driver~~, which supplies~~ for supplying driving currents to the motor, said control circuit comprising means for generating signals representing a ~~computing the~~ position and/or [[the]]a speed of the rotor from the ~~output~~ signals representing the induced voltages ~~provided by said detection means~~.

BRIEF DESCRIPTION OF THE DRAWINGS

[0011] Embodiments of the invention are described in greater detail hereinafter relative to the attached schematic drawings.

[0012] ~~Figure~~ Fig. 1 shows an example of drive currents which can be used to control a synchronous three-phase motor as well as the induced voltage generated in each of three phases [[by]]of the motor ~~rotation,~~ ; and

[0013] ~~Figures~~ Figs. 2a - 2c show different arrangements of [[the]]a device ~~according to~~ consistent with embodiments of the invention for controlling a synchronous three-phase motor with permanent magnets.

DESCRIPTION OF ~~PREFERRED~~ EMBODIMENTS

[0014] ~~Figure~~ Curve a) in Fig. 1 shows ~~in a)~~ an example of [[the]]a drive current that can be used to control one phase of a synchronous three-phase motor. ~~and in~~ Curves b), c), and d) in Fig. 1 show the induced voltages that can be measured in each respective phase when the motor is rotating and the ~~current supply is~~ drive currents are turned off. The induced voltage shown in curve b) of Fig. 1 corresponds to the drive current shown in curve a) of Fig. 1. The drive currents corresponding to curves c) and d) are not shown. There ~~is~~ exists a phase shift from one motor phase to ~~the other~~ another between the corresponding drive ~~current pulses~~ currents, as well as between the respective induced voltages. For a three-phase synchronous motor, this phase shift is equal to 120°. In the example shown in ~~figure~~ Fig. 1, the drive current pulses have a positive value when the induced voltage is positive and a negative value when the latter is negative. This is valid for a positive torque only and, when a negative torque is required, drive current pulses polarities are reversed. Besides, drive current pulses are present for a fraction of each half-period of the induced voltage waveform only. According to ~~figure~~ Fig. 1, this fraction is equal to 120°, starting at 30° after the zero-crossing of curve b), and is followed by a

time period during which the drive current is turned off. This turned-off period corresponds to a motor rotation angle of 60°. The frequency of the drive current pulses is chosen as a function of both the characteristics of the motor and its current status. After the drive current is turned off, for instance at time [[t0]]$\underline{t_0}$, there is a stabilization period δt after which the induced voltage in each motor phase is measured, for instance at time [[tm]]$\underline{t_m}$. From these measured induced voltages, the ~~measured~~ rotor position and rotor speed can be determined. By way of example, the rotor position in a two-axis system can be determined from the induced voltages measured in a three-phase synchronous motor using the following formulae :

[0015] $Ua = V1$,

[0016] $Ub = \frac{V2 - V3}{\sqrt{3}}$,

[0017] where Ua and Ub are two voltages proportional to the two components of the rotor position vector in said two-axis system (i.e., $\sqrt{Ua^2 + Ub^2}$ is proportional to the rotor speed) and $V1$, $V2$, and $V3$ are the measured induced voltages in the three motor phases, respectively. The rotor rotational speed may be advantageously determined by computing the square root of the sum of squares of all measured induced voltages $V1$ to $V3$. It should be noted however that two measured induced voltages only are actually required since the third one can be determined using the equation $V1 + V2 + V3 = 0$. Other methods, well known to those skilled in the art, may also be used, such as derivation of the determined position or calculation of the change in rotor position as a function of time.

[0018] The arrangements shown in ~~figures~~ Figs. 2a to 2c represent different options to connect ~~the detection means~~ a device 10 consistent with embodiments of the present invention to [[the]]a synchronous motor 1 depending on whether a neutral node N (~~figure~~ Fig. 2b) is available or not. However, such a neutral node may be virtual, as shown in ~~figure 2b~~ Fig. 2c. In this latter case, a [[the]] virtual neutral node Nv is derived from an array of three resistors R, which are connected between respective phases A, B and C of the motor and said virtual neutral node.

[0019] Referring now to ~~figure~~ Fig. 2a ~~we~~, ~~can see a~~ synchronous motor 1~~, the~~ has three phases ~~of which are~~ driven by a motor driver 2. The device ~~according to~~ consistent with embodiments of the invention, with the reference number ~~of which is~~ 10, will be referred to as electronic means hereafter. ~~Such electronic~~ Electronic means 10 ~~comprise~~ comprises a detection means 3 and a control circuit 4. The detection means 3 ~~comprise~~ comprises three high-gain differential amplifiers 31 to 33 and three analog-to-digital converters 34 to 36. ~~Every~~ Each of differential ~~amplifier~~ amplifiers 31 to 33 has [[its]] two differential inputs ~~connected~~ each connected to one phase of the motor 1 so as to be able to measure the voltage difference between corresponding motor phases. In one aspect, the gains ~~The gain~~ of ~~these~~ differential amplifiers 31 to 33 are ~~must be~~ high enough to detect the small induced voltages that are generated by the motor 1 when its rotational speed is near-zero.

[0020] The analog output signals of differential amplifiers 31 to 33 are converted into digital signals by A/D converters 34 to 36 before being applied to [[the]] control circuit 4. Advantageously, [[this]] control circuit 4 may include ~~includes~~ a microprocessor, a DSP

or a FPGA. The position and/or speed of the [[motor]]rotor are computed by ~~the~~ control circuit 4 from digital signals outputted by A/D converters 34 to 36. Such computed [[motor]]rotor position and speed will be referred to hereafter as measured [[motor]]rotor position and speed, respectively.

[0021] As previously mentioned, the rotational speed of the [[motor]]rotor may be determined by computing the square root of the sum of squares of the back EMF voltages existing on the motor phases when the driving currents thereof are turned off. This method of determining the rotational speed of the [[motor]]rotor is ~~preferred to~~ better than other known methods because it gives an instantaneous result.

[0022] For the determination of the motor position, the components Ua and Ub, representative of the position vector in a two-axis system, are computed by the control circuit from the back EMF voltages V1 to V3 using the formulae given here above. Then, the measured angular position θ of the rotor may be computed by using the following formula:

[0023] $\theta = \mathrm{arctg}(Ua/Ub)$.

[0024] ~~According to~~ Consistent with embodiments of the present invention ~~the~~, control circuit 4 also comprises a state filter (not shown), to which are applied the measured ~~motor~~ rotor position and/or the measured ~~motor~~ rotor speed and which delivers a filtered ~~motor~~ rotor position and/or a filtered ~~motor~~ rotor speed. With such a state filter, which ~~advantageously~~ may consist in a Kalman filter, it is possible to filter out noise ~~-corrupted signals~~ and/or disturbances that are always present in actual dynamic

systems. Generally speaking, the state filter, or Kalman filter, processes all available measurements, regardless of their precision, to estimate the current value of the variables of interest, with use of any available information about initial conditions of the variables of interest. In the present case, the measured ~~motor~~ rotor position and/or the measured ~~motor~~ rotor speed may be corrupted by system noises or other disturbances, especially when the ~~motor~~ rotor rotational speed is low. ~~The use of~~ A Kalman filter, or any equivalent coherence filter, ~~allows to take~~ takes into account the physical knowledge that, when the rotational speed of the ~~motor~~ rotor is very low, the position of the ~~motor~~ rotor can not change substantially over a short period of time. In other words, when the speed is very low, the rotor position may be assumed to remain constant. Unlike the measured data, such as measured ~~motor~~ rotor speed and position, the filtered data are thus ~~suitable~~ coherent information that can be used to control the motor properly.

[0025] By way of example for the position of the motor, the Kalman filter may be implemented using the following coherence algorithm:

[0026] $X = X_{-1} + (a * V * T + b * dP) \div 2$,

[0027] where

[0028] X is the estimated position at time t,

[0029] X_{-1} is the estimated position at time t_{-1},

~~Xm is the measured position using back EMF voltages at time t_m with ($t_{-1} \leq tm \leq t$),~~

[0030] V is the measured speed using back EMF voltages at time t_m,

[0031] T is the time duration between 2 successive measurements [[(]]t_{-1} and t[[)]],

[0032] dP is the difference between Xm and X_{-1}, where Xm is the measured position using back EMF voltages at time t_m with $t_{-1} \leq tm \leq t$, and the [[such]] difference dP is ~~being however~~ limited to $\pm(c * VT + d)$[[.]], and

[0033] ~~Parameters~~ parameters a, b, c, and d are coefficients that are adapted to adjust the algorithm to the characteristics of the motor.

[0034] Filtered rotor position and/or rotor speed delivered by the Kalman filter are applied to the motor driver 2 via [[the]]a connection 20 to possibly adjust the drive currents sent to the motor 1.

[0035] The coherence algorithm described above is only one of numerous examples ~~that can be used in accordance~~ consistent with the principles of the present invention. Besides, it shall be understood that the state filter designation will encompass any other filtering circuit that substantially achieves the same function as that described above in relation to the state filter.

[0036] ~~Of course this~~ The present invention is not limited to the ~~preferred~~ embodiments described above~~, to which variations~~. Variations and improvements may be made, without departing from the scope of protection of the present patent. More particularly, although the invention has been described with reference to a synchronous rotating motor with permanent magnets and three phases, it will be understood ~~to also apply to one-phase~~ that the method and device consistent with the present invention may also be applied in multiphase rotating motors as well as to synchronous linear motors.

~~LIST OF REFERENCE SIGNS 1 Motor 2 Motor driver 3 Detection means 31-33 Differential amplifiers 34-36 Analog-to-digital converters 4 Control circuit 5 Electronic means~~